Title: Advances in UAV Applications and Propulsion Technologies Drive the Development of UAV Propulsion Standards (White Paper)

Authors: Mike Kass, Len Louthan, Mark DeAngelo, Audra Zeigenfuss

Address:

National Transportation Research Center, Oak Ridge National Laboratory, Knoxville, TN USA 37932
Email: kassmd@ornl.gov

Declarations of Interest: none

Abstract:

The number of small unmanned aerial vehicles (UAVs) used for private and commercial applications is growing exponentially, beyond the domain of hobby enthusiasts. However, standards development has not been keeping up with the applications and technologies now available. The advent of inexpensive battery-powered quadcopters as stable aerial-photography and remote-viewing platforms has expanded the utility of these systems into commercial and private applications for inspection and surveillance. With drone-delivered packages on the horizon, the potential for expansion will be even higher. These developments need to be incorporated into standards being produced for UAVs and propulsion systems.

Topic: Unmanned aerial vehicles (UAVs)

Funding:

This manuscript has been authored by UT-Battelle, LLC under Contract No. DE-AC05-00OR22725 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes. The Department of Energy will provide public access to these results of federally sponsored research in accordance with the DOE Public Access Plan (http://energy.gov/downloads/doe-public-access-plan).

This work used resources of the National Transportation Research Center, a DOE Office of Science User Facility operated by the Oak Ridge National Laboratory. Neither UT-Battelle, DOE, the U.S. Government, nor any person acting on their behalf: (a) make any warranty or representation, express or implied, with respect to the information contained in this document; or (b) assume any liabilities with respect to the use of, or damages resulting from the use of any information contained in the document.

1. Background

The earliest unmanned remote-controlled (R/C) drones were produced during the mid-1930s for use as training targets for aircraft pilots during World War II. Small, gasoline-fueled two-stroke engines were used to power these craft. Truly small UAVs became widespread during the late 1930s with the advent of model R/C craft for hobby enthusiasts. This was popularized by the Model Aircraft Nationals competition in Detroit in 1937. They were powered by single-cylinder, glow-assist engines fueled with a mixture of methanol, nitromethane, and castor oil.

In the 1960s, the United States Navy acquired turbine-powered QH-50 remotely controlled rotorcraft. The QH-50s were equipped with torpedoes to counter distant threats before hostile submarines could get within striking distance of a U.S. ship. In the late 1970s and early 1980s, military interest in Remotely Piloted Vehicles (RPVs) increased due to the potential for more autonomous operation. This new generation of vehicles matured over the years, with advances in control and payloads, and took advantage of the trend toward increased computing power in smaller packages. In general, the propulsion systems did not keep up with the advances in other aspects of RPVs/UAVs/UASs. Many of these vehicles were limited to relatively short missions (e.g., 3 h), and the frequent overhauls were not a major priority. Further advancements brought about smaller vehicles with longer endurance, and the shortcomings of the propulsion systems became more evident.

Industry has worked diligently to bring about changes in UAV propulsion systems. In the past, the overriding consideration was power output, which always seemed to be lacking. Now, fuel consumption and durability are becoming more predominant. These requirements have brought about the need for exacting consistent test standards. Ancillary systems, such as power generation, are receiving deeper scrutiny, as is cooling installation, modularity, and others. As the systems mature, it is necessary to develop standards for design and testing to ensure smooth integration and operation.

2. Propulsion

Steady progress has been made in recent years on the development of unmanned aircraft, both RC and autonomous. Cognizant government agencies are also taking keen interest in the developments with increasing regulations on how these craft are operated in the commercial airspace. While the predominant form of propulsion for this class of aircraft is still based on traditional hydrocarbon fuels, in the future these aircraft are more likely to be powered by electrically driven fans with batteries as the source of power.

Ravi Rajamani [1], in his book *Electric Flight Technology: The Unfolding of a New Future*, explains, “[f]or UAVs, electric propulsion offers unique advantages such as simplicity and convenience, higher safety, ease of transportation, cheaper maintenance, and the elimination of flammable liquids.” For recreational UAVs, the simplicity of battery power effectively supports electric propulsion because speed and flight distance are not the primary roles for these sorts of aircraft. Quadcopters are growing in popularity and being used commercially for photography and videography. Most quadcopters are electrically powered.

Figure 1. Lithium-ion battery system.

3. Power

The components of the propulsion system depend on the power source. The powertrain is the most critical component of a UAV, providing not only the thrust but also the power for instruments, sensors, controllers, and onboard computers. It determines the range, speed, and payload capacity of each UAV. For HC-fueled piston and rotary engines, the propulsion components include the fuel (and potentially lubricant) delivery systems, alternator assembly, linkages, and propeller. For turbine engines, the propeller is not needed for thrust generation. In the past, small UAV propulsion was predominated by internal combustion engines. Cordless electric motors were introduced in 1972 and enabled the use of battery-powered flight. Yet, two-stroke glow-assist engines continued to dominate the industry, as they were inexpensive and of simple construction. This later changed when nickel-cadmium and lithium batteries (Figure 1) provided power options for small UAVs. Battery or solar electrics don’t have the liquid fuels to burn, but do require a battery, wiring, and motor assemblies. The simplicity and handling make battery electrics the preferred option; however, the energy density of batteries remains low. Even with advances in lithium battery technologies, flight times are typically limited to less than 30 min.

Given the wider interest and use of lithium-ion batteries, standards for lithium-ion batteries have gained traction. The use of high-power electric systems such as batteries do not have as many guidance resources, such as standards and information reports, as traditional aerospace hardware and software [1]. However, standards development for batteries have been recently started by industry groups such as SAE International and the Radio Technical Commission for Aeronautics (RTCA) following some recent failures of these battery systems.

As the number of instruments and sensors increase on aircraft, so does the demand for power. Multiple applications require the UAV to have increased payload capacity, speed, response, and endurance. To meet these changes in demand, system designers are turning to hybrid power systems combining hydrocarbon (HC) fuels with battery electrics to improve operational flexibility and increase operational flight time and response. The energy density of HC fuels is around 45 times that of batteries, and today we are seeing aggressive development of hybrid systems. Hybrid concepts are the best approach to higher power and endurance by utilizing the high energy density of hydrocarbon fuels. Hybrid concepts also allow the use of more flexible electric motors which is not achieved by using a single power source. The evolution and integration of hybrid systems can be expected to significantly impact standards development, as does frame structure (fixed, rotary, or combination thereof). For instance, the operational requirements for a single-cylinder two-stroke engine powering a fixed-wing design will be different from a flexible design incorporating hybrid propulsion. As a result, dynamometer-based standards will be foundational for engines and motors. The combination of speed and load requirements on UAV engines and motors produce unwanted harmonics with engine dynamometer testing. As a result, operational protocols will likely need to be developed as part of this effort to enable existing test structures.

Standards should include or simulate the altitude components as well. The development of correction factors, similar to those developed for nitrogen oxide emissions as a function of humidity, may also be developed as part of the standards development effort.

4. Safety and Durability

Rajamani highlights the criticality of building safety into aircraft design. Regulatory authorities demand evidence of system reliability prior to the sale of a transport aircraft, and the certification process is “lengthy, complicated, and expensive” [1]. By building in system redundancy and independence with multiple generators, distribution busses, and actuators, reliability is enhanced and the risk of catastrophic system failure reduced.

Because of the critical nature of propulsion systems to keep airframes aloft and operational, it is paramount that standards be developed to ensure durability and performance. Until recently, engine (or motor) durability was not a major concern. With the possibility of drone-delivered packages, safety and durability will become an issue. Since, historically, the operators of drones were predominantly hobby enthusiasts, the primary issue was affordability. Ironically, this did not change significantly when military applications and uses came to the forefront. Even though the cost of military-grade UAVs is high, the engine has remained a fraction of the cost in spite of the fact that it provides thrust, powers the electronics, and determines heat and noise signatures as well as flight time.

The transmission of electrical energy, while convenient, can be very hazardous [1]. Engineers are being tasked with designing aircraft that adhere to performance specifications while maintaining safety and reliability. Small GA aircraft, potential air-taxi vehicles, require much power to operate and will also require infrastructure on the ground to support these operations. Adding air taxis to the increasing number of electric ground vehicles will have to be considered in designing such an infrastructure.

5. Future Trends

In the immediate future, hybrid power systems utilizing HC fuel engines and battery-electrics are being aggressively pursued. However, other hybrid systems are being evaluated that incorporate fuel cells, solar cells, and turbines. When commercial and private package delivery use is approved, the numbers of UAVs flying overhead are expected to skyrocket. In addition, the variation in design and platforms that will be applying for permits will necessitate standard-based evaluation protocols.

6. SAE Unmanned Aircraft Propulsion Systems Committee

The fueling of a century worth of aerospace industry advancement has helped earn SAE International the position of being the world's largest, most respected aerospace standards development organization. Standards assist in the adoption of emerging technologies, especially in cases where other industries have already fielded products. A good example of this is hybrid propulsion. In the automotive world, these systems have matured, and the standards are in place to ensure safe and reliable operation. By adopting and modifying the existing standards to the needs of the UAS propulsion community it is possible to realize significant progress.

In 2016, SAE International established the Unmanned Aircraft Propulsion Systems Committee (E-39) with the responsibility to develop and maintain standards for unmanned air vehicle propulsion systems. Its scope includes both chemical and electrical propulsion and the supporting systems, encompassing but not limited to engines, servo actuators, fuel, motors, controllers, batteries, fuel cells, wiring, connectors, fluid systems, instrumentation and sensors, power management, filler valves, filters, pumps, propellers, propeller balancing rigs, test stands, thrust measurement rigs, and flight management for energy-efficient flight. This is a broad mandate that covers a very wide range of technologies and requires an equally wide range of capabilities to achieve success.

The UAS industry will benefit by understanding well-defined categories and system types, familiarization of accepted test methods and trusted measurements, and building upon industry best practices and specifications. The committee expects to rely on and expand existing aviation standards but will be required to develop new standards in areas not traditionally related to flight systems, hybrid power being a prime example. This technology has matured in the automotive sector where the related standards are generated and controlled by SAE.

References

[1] Rajmani, R. *Electric Flight Technology: The Unfolding of a New Future.* Warrendale, SAE International 2018; DOI: 10.4271/T-135.